BBC RD 1974/35

1969 1974
THE QUEEN'S AWARD TO INDUSTRY

RESEARCH DEPARTMENT

REPORT

The subjective effect of intermodulation distortion when sound and vision signals are amplified in a common amplifier

P. Shelswell, B.A.(Cantab)

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

October 1974

BBC RD 1974/35
UDC 621.391.832.42
621.391.833.64

THE SUBJECTIVE EFFECT OF INTERMODULATION DISTORTION WHEN SOUND AND VISION SIGNALS ARE AMPLIFIED IN A COMMON AMPLIFIER

P. Shelswell, B.A.(Cantab)

Summary

This report examines the relationship between the subjective and objective effects of intermodulation impairments introduced into 625-line System I television systems, when sound and vision signals are amplified in a common amplifier. The variation of impairment with sound modulation is discussed. No account is taken of the distortion of the sound channel or cross modulation.

Issued under the authority of

P. Rainger

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

October 1974
(RA-133)

THE SUBJECTIVE EFFECT OF INTERMODULATION DISTORTION WHEN SOUND AND VISION SIGNALS ARE AMPLIFIED IN A COMMON AMPLIFIER

THE SUBJECTIVE EFFECT OF INTERMODULATION DISTORTION WHEN SOUND AND VISION SIGNALS ARE AMPLIFIED IN A COMMON AMPLIFIER

P. Shelswell, B.A.(Cantab)

1. Symbols used in the report

a_r	Polynomial coefficients representing the transfer characteristic of an amplifier.
b_r	Amplitude of components of three-tone test signal
dBp	dB relative to peak sync. pulse power
f_c	Frequency of colour subcarrier at u.h.f.
f_k	Frequencies of components of three-tone test signal
f_s	Frequency of sound carrier at u.h.f.
f_v	Frequency of vision carrier at u.h.f.
I_f	Amplitude of intermodulation products at frequency f
r	Order of polynomial term
t	time
v_{in}	Input voltage
v_{out}	Output voltage

2. Introduction

Any non-linearity in the characteristic of an amplifier in the transposer equipment of a television relay station leads to the introduction of impairments into the transmitted signal. The most critical degradations are intermodulation and cross modulation. If sound and vision signals are passed through a common amplifier they interact producing visible and audible distortion.

Some transmitters operate at power levels low enough for transistor amplifiers to be used in place of thermionic devices and the use of transistors is desirable because they are both cheap and reliable. The upper limit to the power available from a transistor amplifier is defined by the level of distortion produced, rather than by the absolute maximum power available. The power transistors used in u.h.f. transmitters are under-run to maintain distortion at acceptable levels. To increase the power output one must either have more powerful transistors or relax the specification of distortion. At present the power handling capabilities of transistors are limited by technological considerations. It is therefore important that the distortion specification is not so strict that it is financially impractical. Conversely it must not be so loose as to lead to a degraded service.

The effects of non-linearity are black crushing, synchronising-pulse crushing, intermodulation and cross modulation. The most important intermodulation product takes the form of a pattern, caused by beats between the sound carrier and the colour subcarrier, whilst the cross modulation appears as buzz on sound due to amplitude modulation of the f.m. sound carrier.[1] Under the present specification, intermodulation is the limiting factor. The allowable level of intermodulation has been under discussion and it was felt that the standard should be reviewed. Work in this field has been reported earlier this year by Harvey[2] who produced results relating the subjective and objective effects of intermodulation. They are only an approximate indication of the level of impairment produced, however, being based on a small amount of data. Before transmission standards could be reviewed a more exhaustive series of tests was necessary.

It is the object of this report to describe and present the result of a series of tests designed to compare the subjective impairments produced by intermodulation with the objective measurement of intermodulation using the three-tone test. The effect of cross-modulation on the sound channel is also investigated. It is also suggested how the results may be applied to produce transmission standards in future.

3. Theory

The sound and vision components of a television signal can be amplified in a common u.h.f. amplifier, but if there is any non-linearity the sound and vision signals interact. The distortion products are at frequencies which are combinations of the sums and differences of the vision and sound frequencies. Although a complete analysis of transistor distortion, involving frequency, amplitude and time dependency, has been published by Narayanan[3] a much simpler approximate approach will be used here.

Over the frequency band occupied by a television channel, the transfer characteristic of an amplifier may be represented by a power series.

$$v_{out} = \sum_{r=0}^{\infty} a_r v_{in}^r \qquad (1)$$

Also the television signal may be approximated by three tones at the vision carrier, the colour subcarrier and the sound carrier frequencies.

i.e.
$$v_{in} = \sum_{k=0}^{\infty} b_k \cos 2\pi f_k t \qquad (2)$$

This test signal is often referred to as the three-tone test signal,[4] the values of f_k and b_k are listed in Table 1.

TABLE 1

Amplitude and Frequencies of Components of the Three Tone Test

k =	1	2	3
f_k (MHz)	f_v	$(f_v + 4{\cdot}43) = f_c$	$(f_v + 6) = f_s$
b_k (dBp)	−8	−17	−7

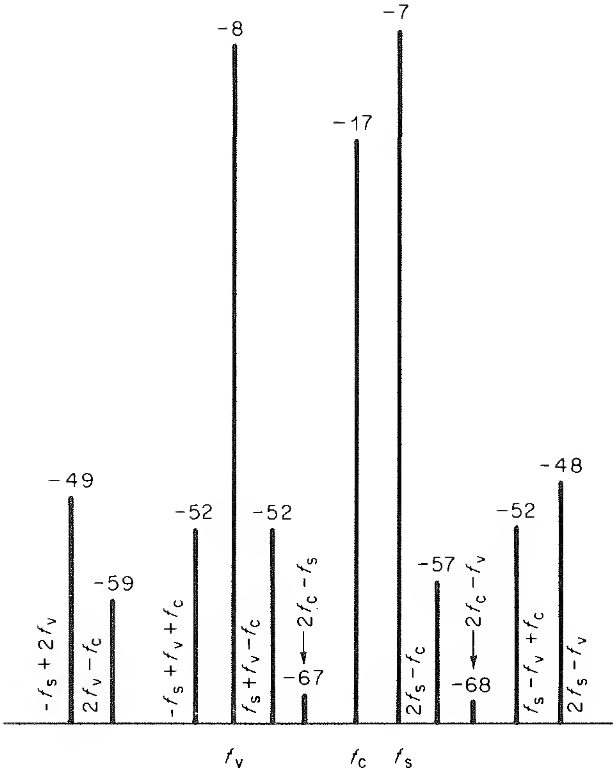

Fig. 1 - The three tone test signal and third order intermodulation products

The expression dBp refers to dB below the peak sync. pulse power level of the equivalent television signal.

Solutions of Equations (1) and (2) have been reported by many authors.[5,6] The even-order terms (those for which r = 0, 2, 4 etc.) produce distortion components which are out of the u.h.f. band and can be filtered out, but the odd-order terms (those for which r = 1, 3, 5 etc.) can produce in-band components. The coefficients a_r normally tend rapidly to zero as r increases and so only the lower orders need be considered. Of these $a_1 v_{in}$ is the direct output and the third order term (r = 3) represents the most significant distortion term. Fifth order terms become significant only if precorrection techniques are used,[7] and will not be considered in this report.

Thus the transfer characteristic reduces to

$$v_{out} = a_1 v_{in} + a_3 v_{in}^3 \qquad (3)$$

When the three-tone test signal is passed through a device with this characteristic, the intermodulation products (i.p.) generated by the third order term lie at the frequencies shown in Fig. 1. Their magnitude is dependent on the ratio a_3/a_1; the values shown in Fig. 1 are the maximum permitted by the current BBC specifications, which restrict the maximum i.p. level within the channel (at $f_v + f_s - f_c$ in this case) to −52 dBp.

Of these i.p.s only three occur within the channel — those at ±1·57 MHz and +2·8 MHz. If a television signal is used in place of the three-tone test signal there will be many more spectral components. The spectra of the transmitted signals are concentrated around the three-tone test frequencies, however, resulting in the intermodulation products lying in the neighbourhood of ±1·57 MHz and +2·8 MHz. It is the ±1·57 MHz i.p. which is most visible, the +2·8 MHz i.p. being of considerably lower magnitude.

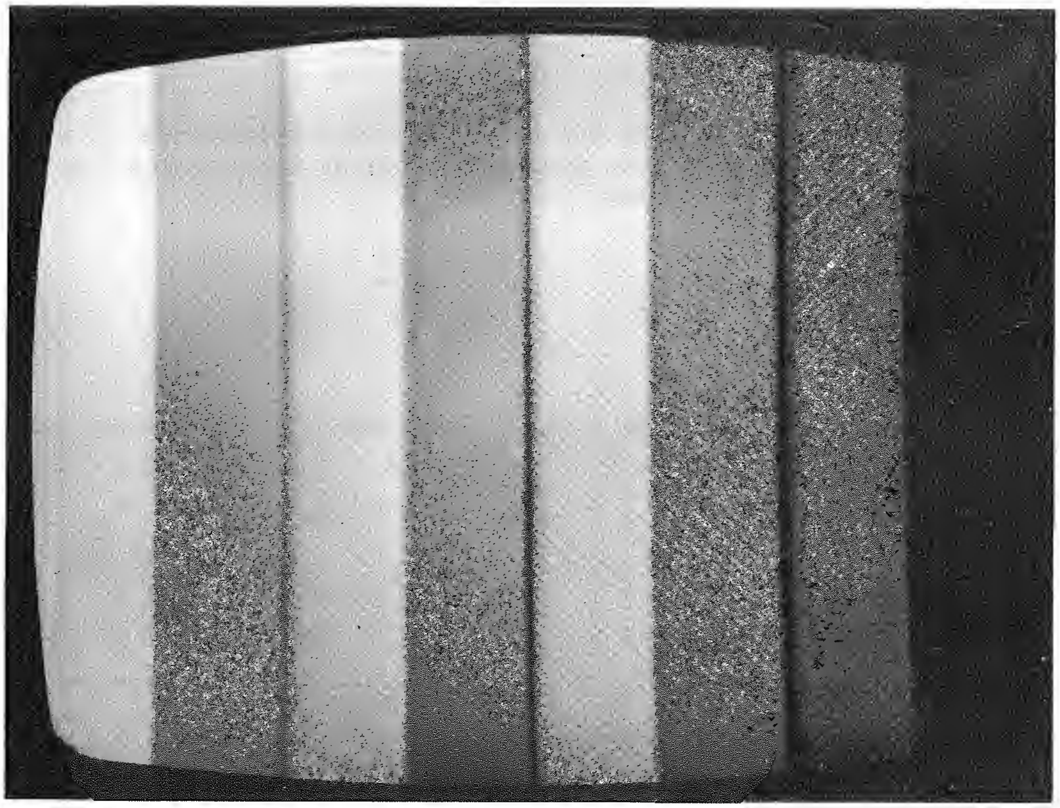

Fig. 2 - Colour bars showing intermodulation distortion with no sound modulation

The magnitude of the ±1·57 MHz i.p. is given by[5,6]

$$I_{1\cdot57} = \frac{3\,a_3}{2\,a_1}\,b_1 b_2 b_3 \qquad (4)$$

Thus it will be greatest in areas of low luminance (high b_1 for a negatively modulated system) and high chrominance (b_2). The sound carrier level should be constant.

Although the intermodulation products may be large in areas of low luminance they may not be most visible there. Two factors combine to produce this result. Firstly the gamma characteristic of the cathode ray tube produces a smaller change in luminance for a given input voltage swing at low levels than at high ones. Secondly the fractional luminance difference required for constant visibility, although constant over most of the luminance range, rises rapidly in dark areas. It has been shown that[8] the combination of these two effects leads to a maximum sensitivity to perturbations occurring at a picture signal level of about 20% peak white. Thus the i.p.s generated in areas of saturated blue are not necessarily more visible than those in areas of saturated red or magenta.

The appearance of the distortion is a series of striations, the precise form of which is dependent on the sound carrier frequency. This has been chosen[9] so that when there is no sound modulation the striations appear as straight lines at approximately ±45° to the horizontal. The sign is dependent on the phase shift given to the PAL subcarrier from line to line. For some colours, e.g. magenta both plus and minus 45° striations are visible (see Fig. 2). The slope of the striation is not radically altered by the the permitted variation[10] of ±500 Hz for the mean sound carrier frequency. When full sound modulation is applied, the deviations in carrier frequency produce variations in the original pattern. If the sound modulation frequency is a subharmonic of line frequency a coherent pattern may emerge, otherwise it will be random. Examples of these patterns are shown in Figs. 3 and 4 respectively.

The pattern may also move up or down as the phase of the i.p. varies from one frame to the next. Once again this is dependent on the mean sound carrier frequency. The 500 Hz permissible deviation from f_v + 5·9996 MHz means that as the carrier frequency is increased, the pattern will vary from stationary to moving, and back to stationary. The maximum possible rate of movement is such that the pattern sweeps across the monitor screen in about three seconds; this is sufficiently slow for the eye to follow without any averaging taking place. The combination of these effects gives rise to a basic pattern which reduces to an incoherent pattern resembling noise when sound modulation is applied. Similar i.p. patterns may be generated by the high frequency luminance information in areas of fine detail. In this case the i.p. may form Moiré patterns with the picture detail and so be more subjectively disturbing. Fig. 5 shows Moiré patterns produced on a test signal designed to illustrate the effect.

The present specification states that the principal i.p. must not exceed −52 dBp when the three-tone test signal is used.

4. Experimental work

In order to correlate subjective and objective effects of intermodulation, two series of tests were performed. Dis-

Fig. 3 - Guardsman picture showing intermodulation distortion with low level hum frequency modulated on the sound carrier

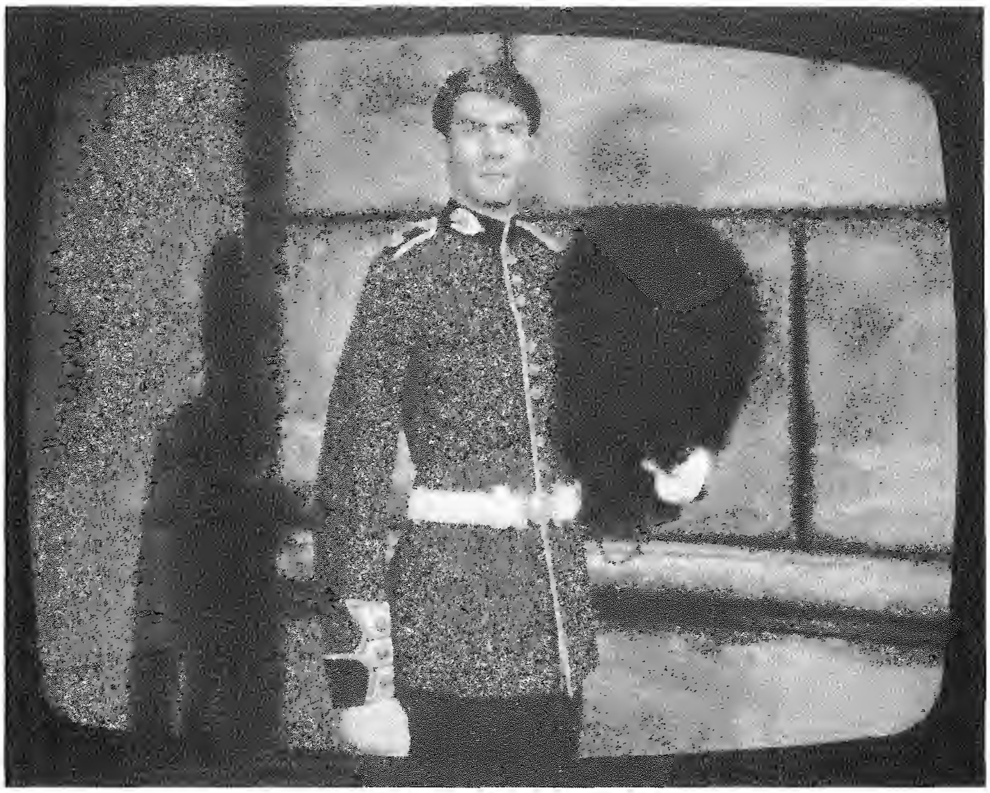

Fig. 4 - Guardsman picture showing intermodulation distortion with full programme modulating sound carrier

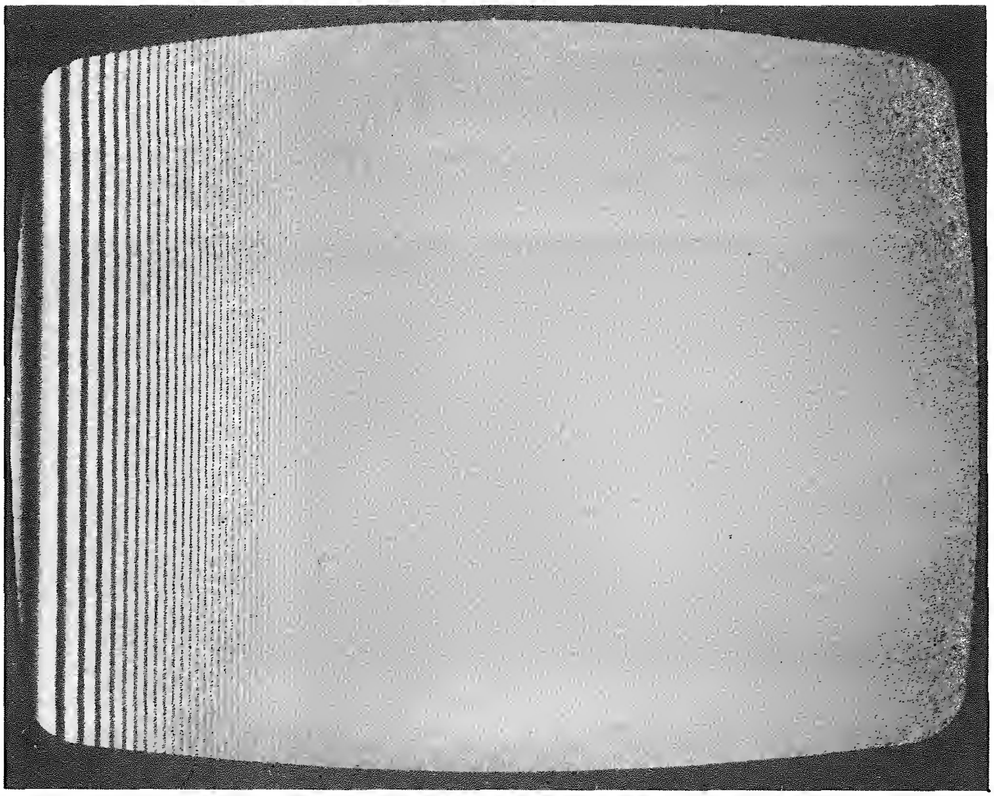

Fig. 5 - Line sweep test signal showing Moiré fringes caused by beating of intermodulation with picture content

tortion was introduced into a u.h.f. television signal by over-driving an amplifier, the level of distortion being controlled by a suitable choice of input power level. This method has the advantage of producing distortions similar to those generated by a relay station with solid state output stages.

Subjects were asked to grade the impairment of the pictures on the six-point impairment scale. In the first series, six different pictures were shown in random sequence, with differing levels of impairment. This series was shown twice, first with low-level hum (about 60 dB below programme) modulating the sound carrier, then with

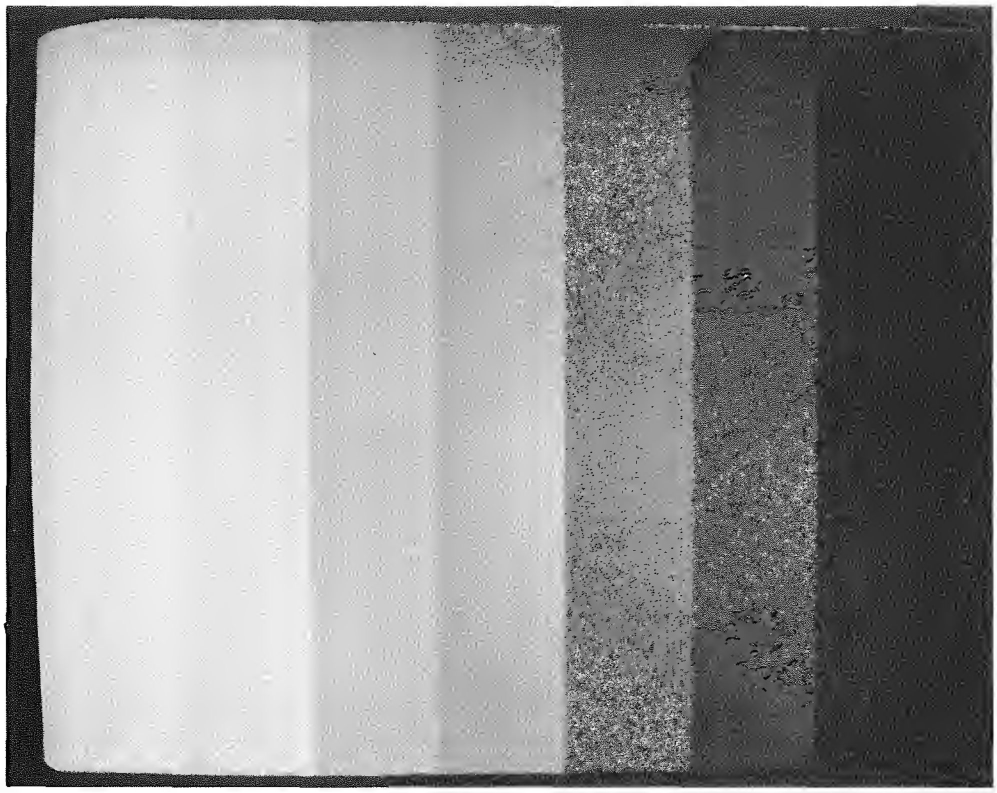

Fig. A1 - Colour bars

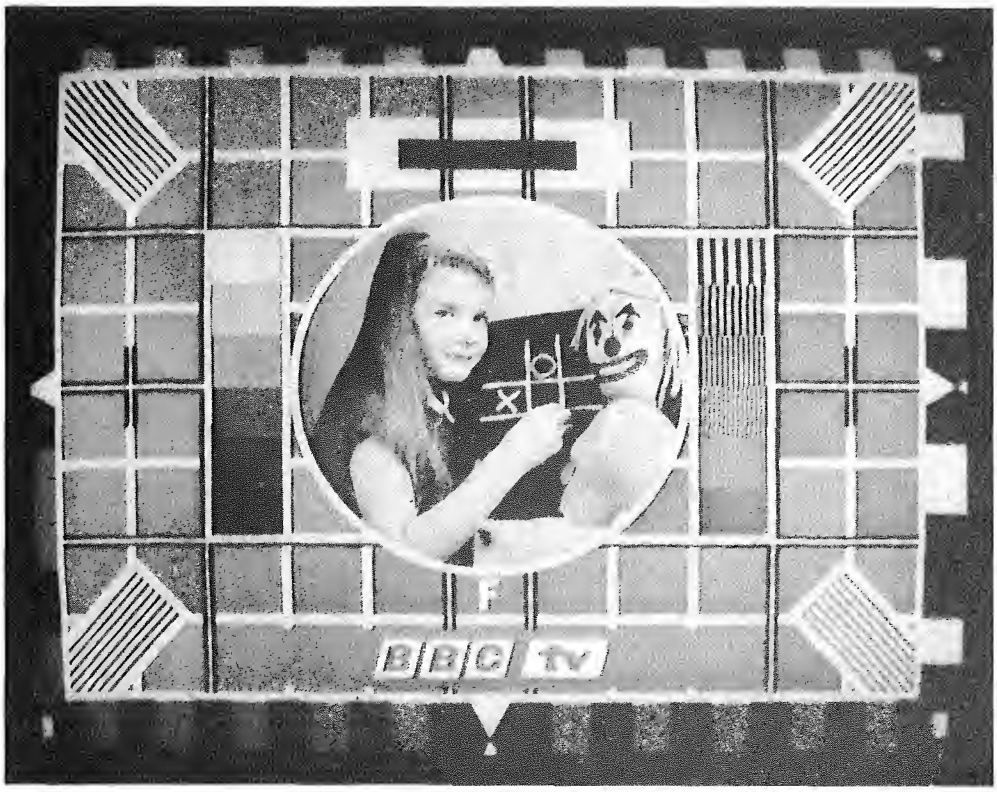

Fig. A2 - Test card F

full sound programme. The results were analysed and two critical still pictures were chosen for further study (colour bars and the Guardsman — Figs. A1 and A6). Subjects were shown these pictures under controlled lighting conditions, again with either low level hum or programme modulating the sound carrier. The mean sound carrier frequency was locked to f_v + 6 MHz.

Full details of the apparatus, test pictures, viewing conditions and impairment scale are given in the Appendix.

5. Results

The results of the first series of tests showed the

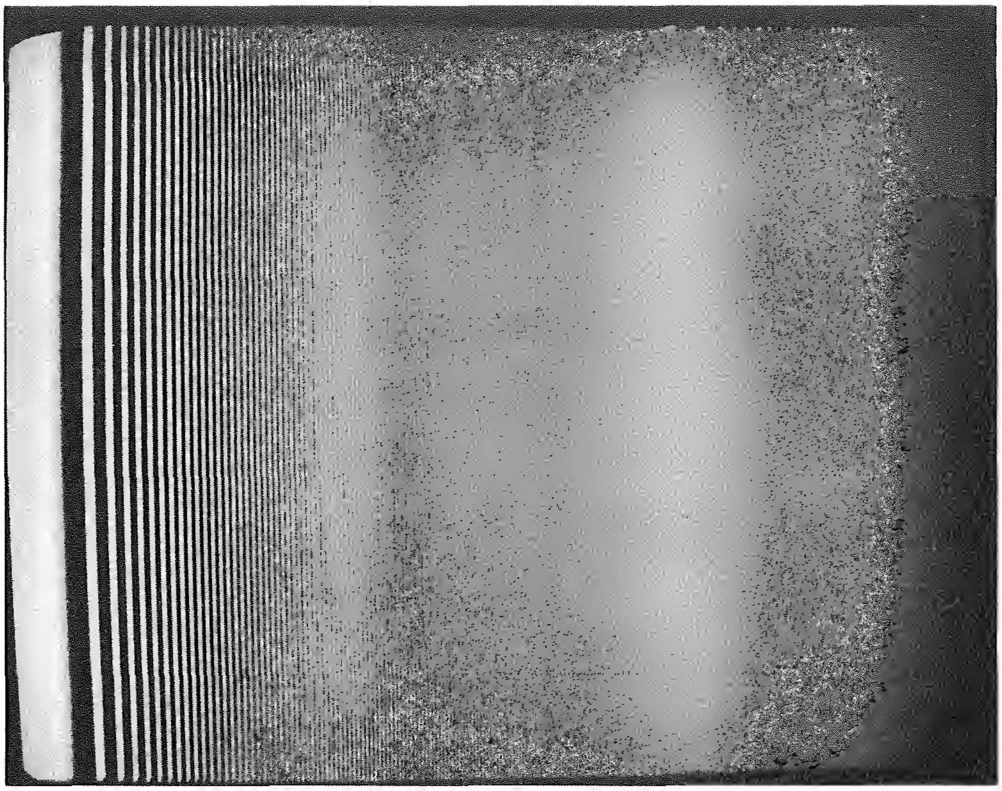

Fig. A3 - Line sweep test signal

Fig. A4 - A pond

dependency of the subjective effect upon the picture content. Those pictures with colour or high-frequency luminance information produced disturbing effects for low i.p. levels whereas scenes without saturated colour, and with little high-frequency content appeared to be most affected by black crushing rather than intermodulation. I.P. levels for grade 2 for each scene are shown in Table 2. (The scenes are shown in Figs. A1 to A6.)

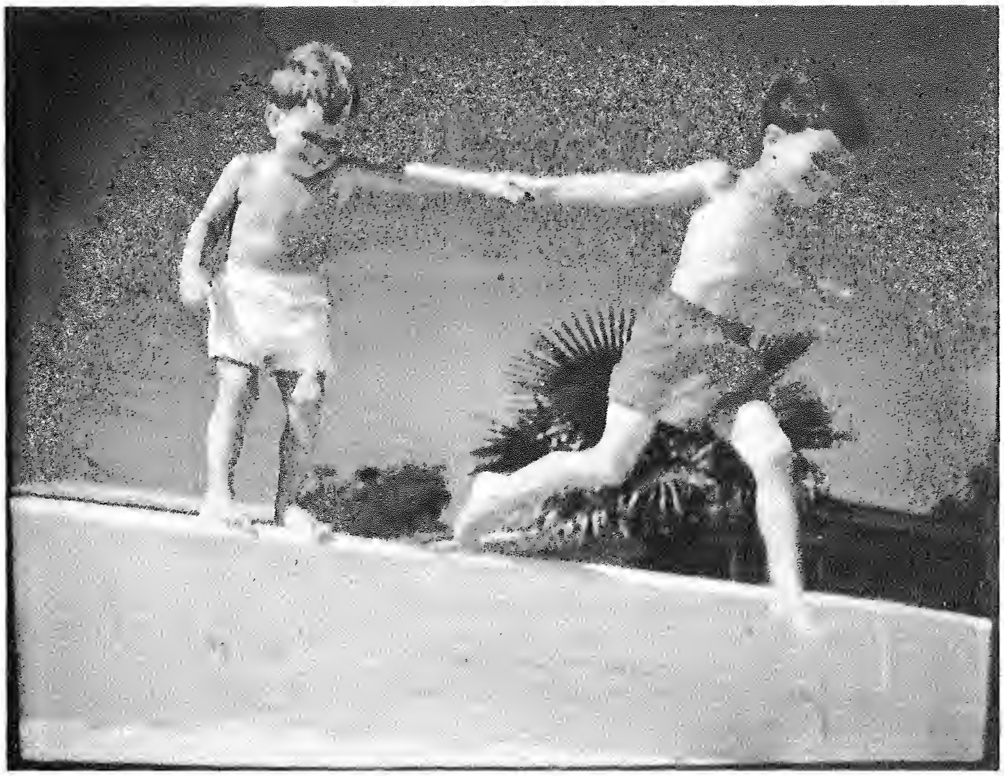

Fig. A5 - Two boys

Fig. A6 - Guardsman

TABLE 2

Variation in i.p. level required for grade 2 impairment. (Low level hum modulation on sound)

Scene	1	2	3	4	5	6
Level of 1·57 MHz i.p. (dBp)	−51	−47	−57	−40	−45	−48

Scene 4 showed little impairment. For an i.p. level of −42 dBp the impairment grades averaged 1·4 both with hum or sound and with full sound programme, no observer found it worse than grade 2. This type of picture is therefore highly non-critical to this form of distortion. Black crushing is more in evidence than intermodulation.

The line sweep test signal (Scene 3) showed severe impairment even at low i.p. levels. At −52 dBp the i.p. formed Moiré fringes with the original pattern giving an average grade of 3·7 with hum modulation. At −58 dBp the average grade given was 1·9 with several observers giving gradings worse than 2.

Test card F and Scene 5 are not very critical, there being little saturated colour in them.

The colour bars and the picture of the Guardsman are critical.

A second series of tests was performed to increase the accuracy and extend the range of the first. There was no significant difference between the results obtained from the two series of tests and so the results have been combined. These results are shown in Figs. 6 and 7.

The standard deviation of the results at grade 3 was about 0·7 of a grade. The difference between the two curves for hum and full programme modulation is statistically significant for i.p. levels greater than −48 dBp. The variation in results between technical and non-technical observers was not significant.

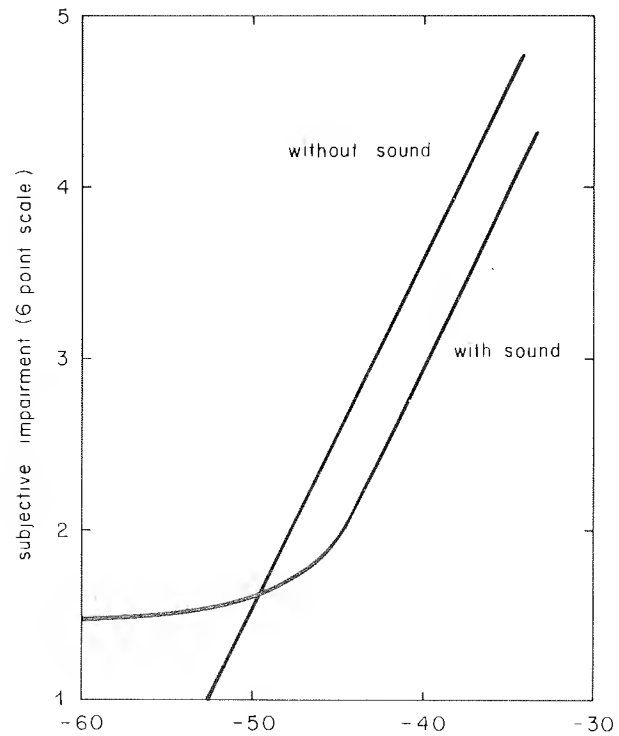

Fig. 6 - Variation of subjective impairment with i.p. level for the Guardsman picture

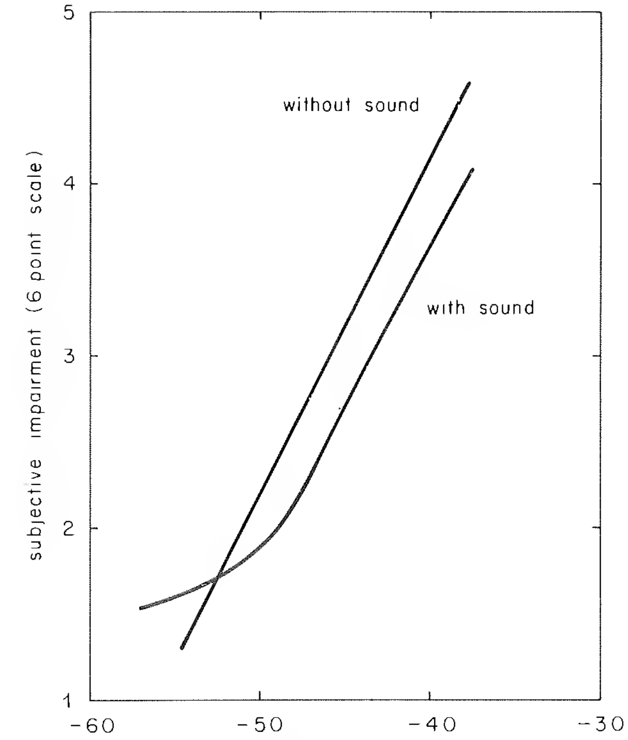

Fig. 7 - Variation of subjective impairment with i.p. level for colour bars

6. Discussion of results

The subjective visibility of intermodulation distortion is dependent on the picture content and on the accompanying sound programme modulation. Scenes with little saturated colour could withstand high i.p. levels (−40 dBp on the three tone test) with little noticeable degradation. Those with high frequency content were highly critical, due to the presence of Moiré pattern. High frequency content may also give rise to cross colour, which is objectionable and which may mask the Moiré pattern. The proportion of time during which the high frequency content of a scene would produce objectionable Moiré patterns but no cross colour, is so small that cross colour remains the major problem in this case.

For critical scenes with large areas of saturated colour there is a consistent relationship between subjective impairment and i.p. level (see Figs. 6 and 7). An i.p. level of −52 dBp is equivalent to a grade of 'just perceptible' in areas of fully saturated colour. Above these levels the subjective impairment appears to worsen by about 1 grade for every 5 dB increase in i.p. level. The areas most susceptible to intermodulation distortion were saturated reds. This is consistent with the results of Newell and Geddes[8] described in Section 3.

There is a distinct subjective improvement when the sound carrier is modulated with programme rather than hum, the difference being about ½ grade or 2½ dB in i.p. level. This difference may be attributed to the visible form of the i.p. under different conditions as discussed in Section

2. With no sound modulation the i.p. appears as straight striations (Fig. 2.).

When the sound carrier is modulated with hum (at levels likely to be found in service equipment) the striations bend, forming a repetitive pattern of sweeping curves (Fig. 3). If the pattern is broken up by the addition of programme to the sound channel the striations shimmer and at low levels appear rather like random noise (Fig. 4). The lack of coherence of the pattern under these conditions makes it less noticeable or objectionable. This is in agreement with results on impairments previously reported.[8] The lower limit of grade 1·5 for the impairment with full sound programme (Figs. 6 and 7) may be explained by the similarity of the impairment to random noise. The random noise introduced by the receiver could have been mistaken for intermodulation products in the fully modulated case but not when the pattern was coherent. Thus in this case the limit is the subjective impairment of the receiver noise not the intermodulation.

The results of the tests described in this report can be compared with similar work.[2,11,12] The results of a series of tests at Designs Department carried out in 1964 for the PAL system lie midway between those reported here for colour bars and the Guardsman picture.

Harvey's results[2] are based on one observer (himself) with a limited range of picture material. The subjective impairment produced for a given i.p. level is less than that reported here, especially for the higher gradings, there being a difference of about 1½ grades at an i.p. level of −40 dBp. The reason for this is that for this type of impairment Harvey would appear to be a non-critical observer. The subjective gradings he gave in the tests described in this report were consistent with the results of his own tests, but noticeably more favourable than average at high levels of distortion.

A German paper[11] gives examples of Moiré fringing, and suggests a figure for i.p. level of −51 dBp as a suitable specification for high quality transmissions.

An IBA paper[12] looks at the subjective impairment of cross modulation, and tries to relate cross modulation and intermodulation mathematically. Because these distortions introduce different types of impairment the results are not valid for intermodulation. However, the results indicate that for levels of intermodulation product greater than −40 dBp the dominant distortion is black crushing. In such cases the synchronising pulses would also be crushed. Therefore, the results given in this report cannot be used in isolation when specifying transmission standards which would lead to intermodulation products at levels greater than about −40 dBp.

The results of the tests show that the allowable intermodulation, as measured on the three tone test, is directly related to the allowable subjective impairment. If a critical scene is used as a reference, the variation of distortion permissible for a given grading is as in Fig. 8. (This is the result of 100% colour bars with hum modulation on the sound carrier).

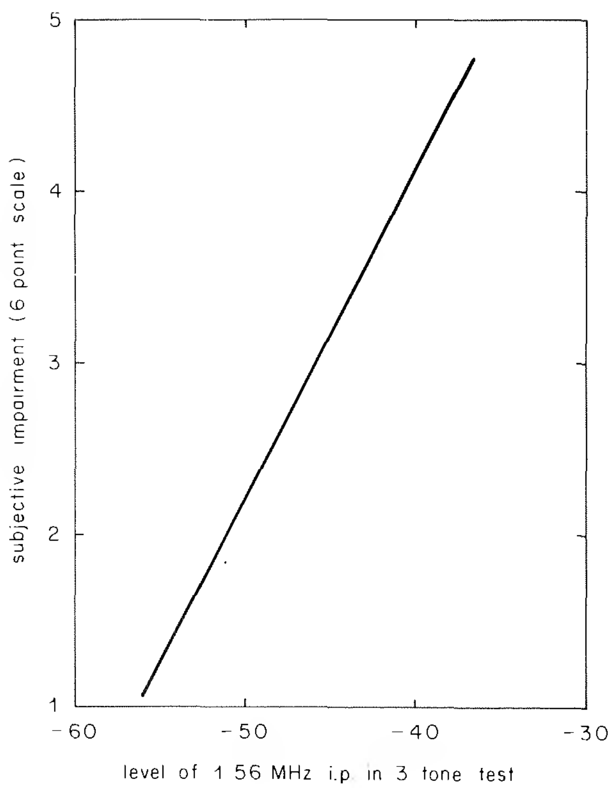

Fig. 8 - Suggested allowable i.p. level for a given grading

This result indicates that for a high quality transmission with a limit of −52 dBp on i.p. a critical scene will give an amount of distortion which is 'just perceptible'. Most other scenes will produce less distortion. Thus the present standard for high quality transmissions cannot be relaxed without introducing a noticeable degradation in quality; to tighten them would of course increase the cost of transmitting equipment.

It may be decided that, under certain circumstances, a subjective grade worse than 'just perceptible' can be permitted. Fig. 8 shows the maximum level of i.p. as a function of the subjective grade. For example, permissible degradations of grades 3 and 3½ would give rise to intermodulation limits of −46 dBp and −43 dBp respectively.

It is important to note that these limits do not take into account any distortion introduced by sync pulse crushing, black crushing or buzz on sound. Any such limits should not be specified without a review of these problems.

The major difference between previous tests and those reported here is that the effect of sound modulation has not previously been fully investigated. As has been shown, the effect is to reduce a coherent pattern to one which more closely resembles random noise, and which is therefore less disturbing.

7. Conclusions

The relationship between the subjective impairment and objective magnitude of intermodulation has been investi-

gated. A law relating the subjective grade allowable and the corresponding level of intermodulation produced when measured on the three tone test has been proposed. This law takes no account of sync pulse crushing, black crushing or buzz on sound which become significant at high i.p. levels.

F.M. sound modulation is shown to reduce a coherent i.p. pattern to an incoherent pattern more resembling random noise, which is subjectively less visible.

The results are only applicable to systems which do not use precorrection.

8. References

1. BROWN, A. 1971. A brief investigation into the permissible amplitude modulation of a u.h.f. television sound carrier. BBC Research Department Report No. 1971/16.

2. HARVEY, R.V. 1974. UHF television: impairments to domestic reception with envelope and synchronous detectors caused by carrier phase perturbation in relay transmitters. BBC Research Department Report No. 1974/5.

3. NARAYANAN, S. 1967. Transistor distortion analysis using Volterra series representation. *Bell Syst. Tech. J.*, 1967, **XLVI**, 5, pp. 991 – 1024.

4. British Standard 4478: 1969. Methods of measurement of intermodulation products in electronic tubes or valves intended for use in colour television transposers.

5. WASS, C.A.A. 1948. A table of intermodulation products. *Proc. IEE*, 1948, **95III**, 33, pp. 31 – 39.

6. LOTSCH, H.K.V. 1968. Theory of non-linear distortion produced in a semiconductor diode. *IEEE Trans Electron Devices*, 1968, **ED–15**, 5, pp. 294 – 307.

7. LYNER, A.G. *and* SHELSWELL, P. 1974. UHF amplifiers: improvement of linearity by precorrection. BBC Research Department Report in course of preparation.

8. NEWELL, G.F. *and* GEDDES, W.K.E. 1963. The visibility of small luminance perturbations on television displays. BBC Research Department Report No. T-106, Serial No. 1963/18.

9. HARVEY, R.V. 1966. Visibility of sound chrominance pattern with the PAL system: dependence upon offset of intercarrier frequency and upon sound modulation. BBC Research Department Report No. G-102, Serial No. 1966/30.

10. Specification of television standards for 625-line System I transmissions. London, IBA/BBC, 1971.

11. RÖSLER, A. 1966. Intermodulation und Kreuzmodulation in Fernseh-Antennenverstärkern. Rundfunktech. Mitt., 1967, **11**, 3, pp. 176 – 179.

12. MORRIS, J.W. 1970. The relationship and measurements of cross modulation and intermodulation on combined signal working CCIR System A V.H.F. Band III relay systems. IERE Joint Conference on Television Measuring Techniques, 1970, pp. 297 – 318.

Appendix

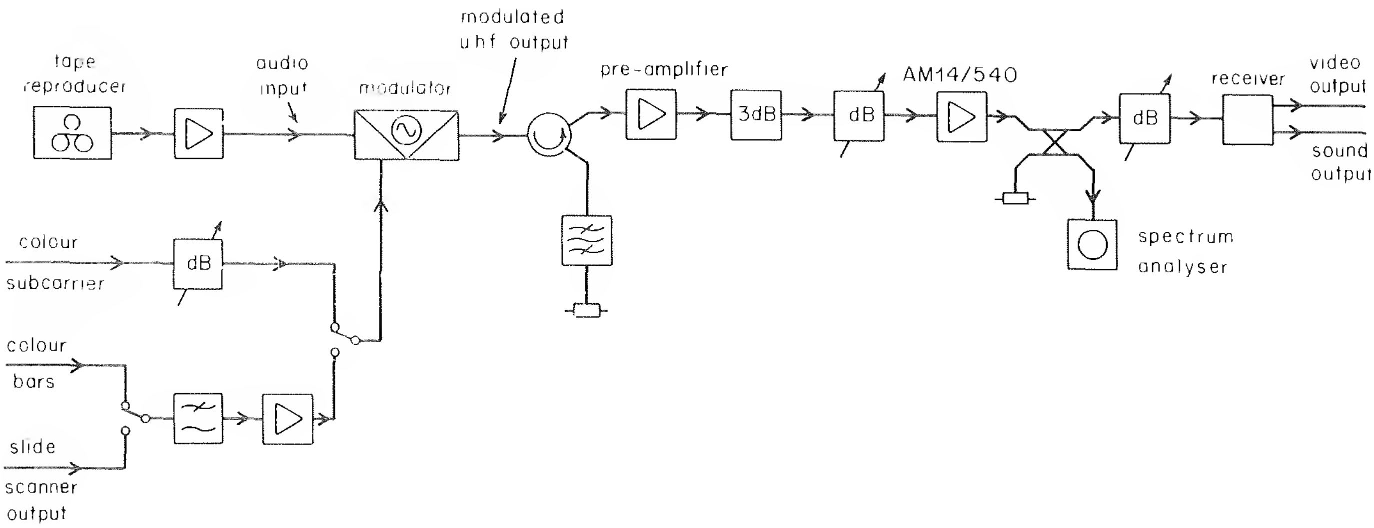

Fig. A7 - Experimental apparatus for subjective tests

1. Experimental apparatus

A schematic diagram of the apparatus used is shown in Fig. A7. It can be divided into three operational blocks.

The first generates an u.h.f. signal (625-line System I) on channel 38 (and includes all units up to the output of the pre-amplifier). The signals from the sound source (a tape recorder) and the video source (a high quality slide scanner, an electronic waveform generator or a sine wave source) are passed through a buffer amplifier and fed into a u.h.f. modulator which is fitted with a vestigial-sideband filter. The local oscillator frequency is filtered from the modulator output and the signal brought up to a suitable level using a commercial aerial pre-amplifier. The i.p. level at this point is better than −65 dBp.

The second operational block generates the i.p. This is done by feeding an amplifier (an AM 14/540) at various input levels. Over the range of input levels used, the magnitude of the f_v + 1·57 MHz i.p. could be varied from −38 dBp to −58 dBp. For every 1 dB increase of input level the i.p. level rose by 3 dB over this range of operation, indicating that the transfer characteristic of the amplifier could accurately be approximated by Equation (3), i.e. there were no significant fifth order effects.

The third operational block monitors the output of the second. The monitoring receiver used had no automatic gain control, and so it was necessary to keep the input level constant manually, the signal and i.p. amplitudes being monitored on a spectrum analyser. The receiver output was viewed on a high quality colour monitor fed from a GEIL/528 decoder. A low quality sound output was also available. The input to the receiver was adjusted so that no intermodulation was visible on the monitor when a clean signal was fed to the input.

2. Calibration

When a 4·43 MHz sine wave was fed to the modulator in place of a video signal the output comprised a three tone test signal with the addition of a vestigial sideband. The magnitude of the vestigial sideband components was not sufficiently large to effect the magnitude of any i.p. generated by the three major tones. This enabled the attenuators before and after the AM14/540 to be calibrated in terms of the three tone test signal before the subjective tests. When a video signal was used in place of the side wave the amplitude at the peak of the synchronising pulse corresponded to the reference level of the three tone test. Thus the results of the three tone test are directly comparable with the results of the subjective tests.

3. Viewing conditions

There were two series of tests. The first series was not carried out under controlled lighting conditions. The second was such that the peak white level was 60 Cd/m^2 with the ambient lighting giving a black level of 0·3 Cd/m^2. The observers were seated in groups of 4, 5 or 6 at distances from the monitor screen between 5 and 6½ times picture height.

The subjects were first shown examples of the impairment they could expect to see. During the tests an unimapired version of the picture was displayed before and after the impaired version, which was shown for 20 seconds. There were 36 tests in the first series and 18 in the second. The pictures and degrees of impairment were chosen at random.

4. Test programmes and their sources

Six still test pictures were used. They are listed in Table 3.

TABLE 3

Test Scenes and Their Source

	Picture	Source
1.	100% colour bars	electronically generated
2.	Test card F	slide scanner
3.	Line sweep	electronically generated
4.	A pond	slide scanner
5.	Two boys	slide scanner
6.	Guardsman	slide scanner

The sound programme used was a recording of a Goon Show.
All pictures were used in the first series of tests.
Pictures 1 and 6 were used in the second series.

5. Subjective impairment grading

1. Not noticeable
2. Just perceptible
3. Definitely perceptible but not disturbing
4. Definitely perceptible and disturbing
5. Highly objectionable
6. Unusable

SMW/JUC

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey